## EXECUTIVE SUMMARY

# FINAL REPORT ARTI-21CR/610-20060-01
# High Condensing Temperature Heat Transfer Performance of Low Critical Temperature Refrigerants


A comprehensive study of heat transfer and pressure drop of refrigerant blends R410A and R404A during condensation and supercritical cooling at near-critical pressures was conducted. Local heat transfer coefficients and pressure drops were obtained at five nominal pressures: 0.8, 0.9, 1.0, 1.1 and 1.2 $\times P_{crit}$. Refrigerant R410A was tested in commercially available horizontal smooth tubes of 9.4 and 6.2 mm I.D., whereas R404A was tested in a 9.4 mm I.D. tube. Heat transfer coefficients were measured using a thermal amplification technique that measures heat duty accurately while also providing refrigerant heat transfer coefficients with low uncertainties. For condensation tests, local heat transfer coefficients and pressure drops were measured for the mass flux range $200 < G < 800$ kg/m$^2$-s in small quality increments over the entire vapor-liquid region. For supercritical tests, local heat transfer coefficients and pressure drops were measured for the same mass flux range as in the condensation tests for temperatures ranging from 30 – 110$^{o}$C. The average heat transfer coefficients uncertainties in this study were 10%, while average pressure drop uncertainties were 2% except at extremely low mass fluxes ($G = 200$ kg/m$^2$-s). For both phase-change condensation and supercritical cooling, frictional pressure gradients were calculated by removing the contraction and expansion component at the ends of the test section and the deceleration component due to momentum change from the measured pressure gradients.

The condensation tests showed increasing heat transfer coefficients and pressure drops with quality and mass flux. The effect of reduced pressure on heat transfer coefficients is not very significant, while this effect is more pronounced in the pressure gradient, with pressure drops being lower at higher reduced pressures. The data from this study were compared with the available heat transfer and pressure drop models in the literature for similar situations, and explanations for agreements/disagreements were provided. In general, no correlation from the literature was successful in predicting heat transfer or pressure drop under the present conditions with an acceptable degree of accuracy, primarily because the available correlations were developed for different geometries, fluids, or operating conditions. In the absence of other applicable flow regime transition criteria, the criteria developed by Coleman and Garimella (2003) for condensation of R134a were used to designate the prevailing flow regimes for a given combination of mass flux and quality. The condensation data collected in the present study were primarily in the wavy and annular flow regimes. Thus, wavy flow and annular flow heat transfer models were developed. A transition region was then defined to provide a smooth transition between the wavy and annular flow models and thereby remove discontinuities in the overall predictions. To predict the condensation pressure drop data, a modified form of the Friedel (1979) two phase multiplier model was developed in this study. The average absolute deviation of the entire data set from the heat transfer model predictions was 6%, with 95% of the data predicted within ±15%. The pressure drop model resulted in an average deviation of 7%, with 90% of the data predicted within ±15%.

In supercritical cooling, the sharp variations in the thermophysical properties in the vicinity of the critical point were found to have substantial effect on heat transfer coefficients and pressure drops. Due to these abrupt property variations, the heat transfer coefficients show sharp peaks while pressure drops show sudden jumps near the critical temperature. Based on the variations of the specific work of thermal expansion (contraction) for each fluid, the data from the supercritical tests were grouped into three regimes: liquid-like, pseudo-critical transition and gas-like. Supercritical heat transfer coefficient and pressure drop correlations for each regime were developed. The average absolute deviation of the entire data set from the heat transfer model predictions was 14%, with 83% of the data predicted within ±25%. The pressure drop model resulted in an average deviation of 15%, with 87% of the data predicted within ±25%.